

# CURRENT STATUS OF RAPID, THE UNIVERSITY OF TOKYO

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## Abstract

The 1.7MV tandem accelerator RAPID (Rutherford Backscattering Spectroscopic Analyzer with Particle Induced X-ray Emission and Ion Implantation Devices), the University of Tokyo has been dedicated to various scientific and engineering studies in a wide range of fields by the ion beam analysis availability, including RBS (Rutherford Backscattering Spectroscopy), PIXE (Particle induced X-ray emission) and ion implantation. Total accelerator operation time amounted 9,358 hours since its installation with the highest annual operation time recorded in 2007. RAPID-PIXE analysis system has been contributed to many environmental studies by analyzing elemental composition of water and sediments samples. It is also applied to the analysis of several cultural heritages such as a works of gilded frame from Renaissance in Italy. Recently, the low level ion irradiation system was also developed and applied for the study of CR-39 track detector with proton beam.

## INTRODUCTION

RAPID (Rutherford Backscattering Spectroscopic Analyzer with Particle Induced X-ray Emission and Ion Implantation Devices) is an elemental analysis and the ion implantation system using ion beams accelerated by an electrostatic accelerator at the University of Tokyo, Japan. The system consists of a 1.7 MV tandem accelerator (Tandetron™, Model 4117-HC, provided by HVEE: High Voltage Engineering Europe corp., Netherlands), two negative ion sources (a Cs sputter solid ion source and “Duoplasmatron” gas ion source) and three beam lines (Figure 1 and Table 1).

The 1.7 MV “Tandetron™” has Cockcroft Walton type

charging system. The terminal voltage is monitored and stabilized by a Generating Volt Meter (GVM). Various ion species can be produced by the dual negative ion sources system. Totally 24 ion species, from Hydrogen to Gold, had been generated and accelerated. Especially it is one of specific features of RAPID that He<sup>-</sup> ion is available by the “Duoplasmatron” gas ion source. PIXE detector system, RBS&ERDA detector system and Ion implantation chamber are equipped at the end of each beam line. PIXE chamber is mounted with three axis and one translation sample manipulator with Si(Li) detector. RBS chamber is mounted with three axis goniometer and silicon surface barrier detector. Recently ERDA system is also set up in the RBS chamber. The angle of Ion implantation line is fixed at -7 degrees to the central axis of the accelerator. A target holder of ion implantation can be heated up to 800 degrees.

RAPID was installed in 1994 at Research Center for Nuclear Science and Technology, The University of Tokyo at first and since then it had been used for various research fields using ion beams. As the Center was reorganized to be a department of School of Engineering in 2005, the educational utilization came to be an important mission of RAPID. Besides several application studies with PIXE analysis, environmental analysis (pond sediments and atmospheric SPM (Suspended Particulate Matter)) is performed as a student experiment. Heavy metal elements analysis of gilded frames of art works from Florence, Italy is also one of recent topics. Another major topic is that a special beam irradiation system was developed to evaluate the response of CR-39 track detector to low level radiation.

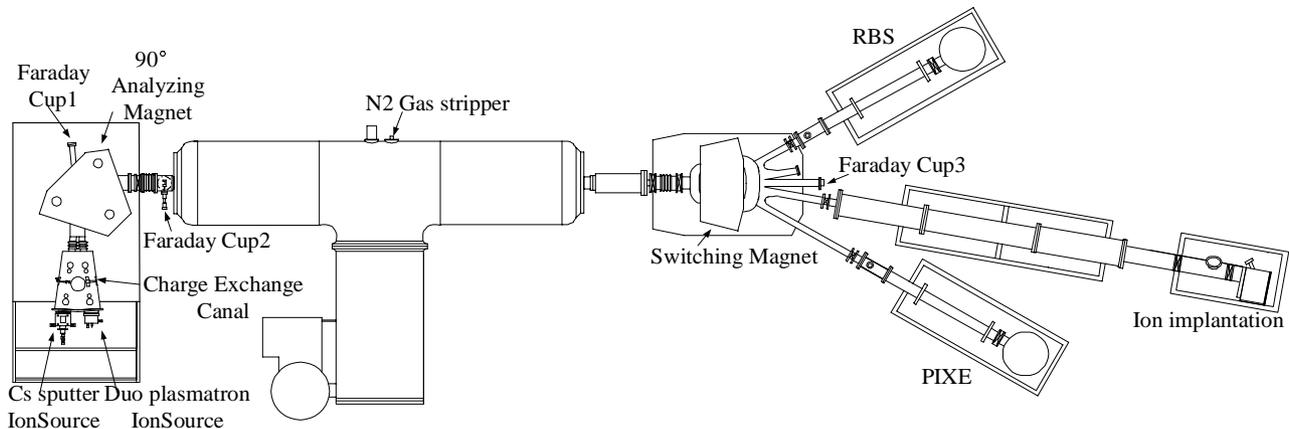


Figure 1: Schematic illustration of the 1.7 MV tandem accelerator system.

Table 1: Specification of RAPID

Negative ion Sources	
Cs sputtering Type	
Extraction Voltage	20kV
Duoplasmatron Type	
Extraction Voltage	20kV
Top Accelerator	
Available voltage range	0.1-1.7MV
Stability	< 80 Vrms
Ripple	< 30 Vrms
Produced beam current	
H <sup>+</sup>	25 μA (3.4 MeV)
He <sup>2+</sup>	2 μA (5.1 MeV)
Si <sup>2+</sup>	140μA (5.1 MeV)
Au <sup>2+</sup>	60 μA (5.1 MeV)
Cu <sup>2+</sup>	20 μA (5.1MeV)
N <sup>2+</sup>	19μA (5.1 MeV)



Figure 2: The percentage of various research fields in 2007.

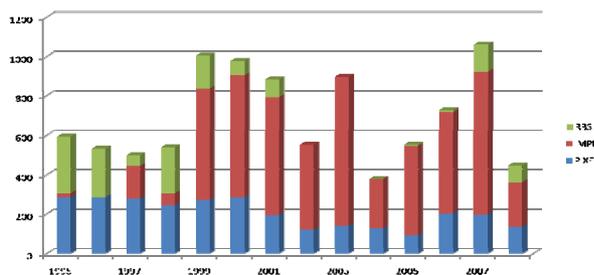


Figure 3: Yearly operation time for each beam lines since 1995.

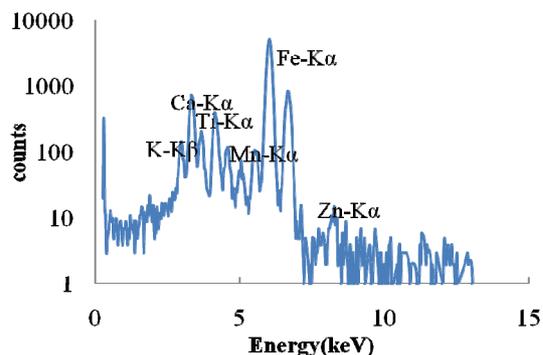


Figure 4: PIXE spectrum of pond sediment. This is that of “Sanshiro-ike” pond in the University of Tokyo.

Figure 2 shows the percentage by which each application field occupies the RAPID machine time. Figure 3 shows the yearly accelerator operation time of RAPID. Considerable drop in operation time in 2008 is due to the off-line development for low level irradiation system and new ERDA system. The total operation time has reached to 9358 hours. Since RAPID had been operated carefully, it had never experienced a severe sparking not a fatal discharging so far. That’s why the main accelerator tank had never opened since the construction.

## APPLICATIONS

### PIXE Analysis of Pond Sediments and Air Dust

PIXE is a good example for understanding the basics of the IBA technique and is easily applied for the environmental study. Hence, a student experimental program was designed with PIXE analysis of environmental samples. Main subject of the program is simply the PIXE analysis of the pond sediments collected from the bottom of a “Sanshiro-ike” in the University of Tokyo which various plants and creatures are living [1].

However it contains from the field work, sampling, pre-treatment for the IBA, PIXE analysis itself and detailed analysis of the data. Students are expected to recognize the relation between human and natural bio system as well as the acquisition of the PIXE technique through this program.

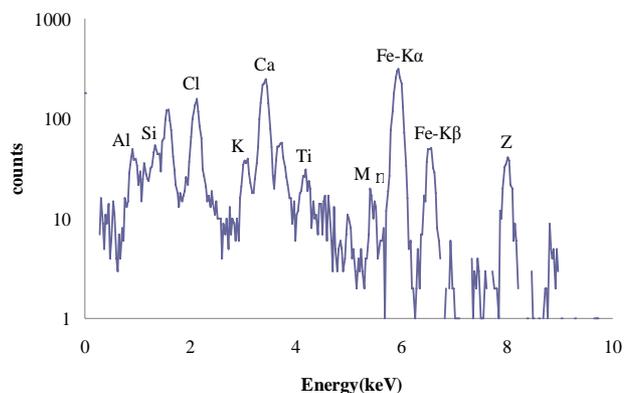


Figure 5: PIXE spectrum of SPM corrected in the campus of University of Tokyo.

Figure 4 shows an example of the PIXE analysis spectrum of m the bottom of a pond named “Sanshiro-ike” in the University of Tokyo around which various plants and creatures are lithe pond sediments. Fortunately, pollutant metal such as Cd, As, Hg was not observed. In 2009, newly designed student experiment program was started which treats SPM (Suspended Particulate Matter) in the atmosphere. Atmospheric dust particles larger than 0.45 micro-m size were collected by a hand-made dust collector at the rooftop of the accelerator building. The main component of the dust around Tokyo area is 1) natural soil, 2) volcanic ash, 3) artificial origin dust due to such as the exhausted gas from the automobiles or

factories, 4) Sea salt and 5) Yellow sand from Chinese continent.

The amount and the portion of these components varies with the seasons and the weather. For example, amount of the yellow sand arriving Japan is greatly enhanced during the term from February to May. The PIXE spectrum of SPM collected at April 1<sup>st</sup>, 2009 is shown in Figure 5. The main components of the yellow sand, Si, Al, are detected.

### Analysis of Cultural Heritage

Cultural heritage is also an interesting target for PIXE analysis concerning with the study of the history of “art”. Here, the analysis of the gilded frame at Florence, Italy is shown as an example. After the Renaissance era, the frame came to be used with paintings. Dr. Sumiko Hasegawa recognized the historical importance of this fact and considered that people of the Renaissance era began to recognize the importance of the frame. They found that a frame could enhance the fascination of the painting by the frame, i.e., excellent morphological design and coloring of the frame makes the painting more

attractive. With such recognition, precious material such as gold came to be used (Figure 6 and Figure 7) [2].

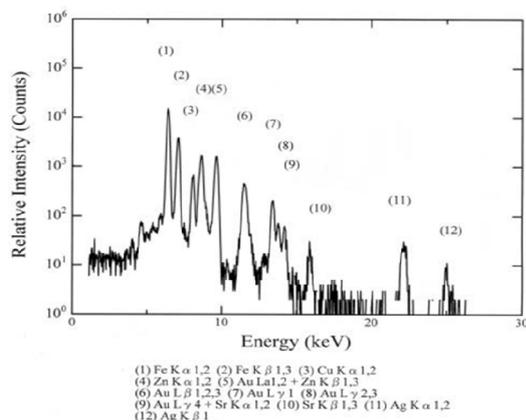


Figure 6: PIXE spectrum of the gilded frame of art works including one from Florence.

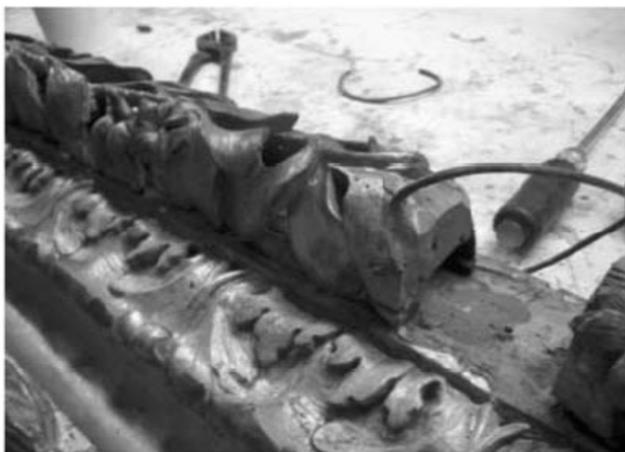


Figure 7: A gilded frame being restored (left) and pieces of impress gold foil on (right).

### Development of Low Level Irradiation Chamber

To evaluate the response of CR-39 track detector to low level irradiation, specially designed irradiation chamber system was developed and set at the ion implantation line of RAPID. If we receive accelerated proton beam directly, it is difficult to reduce the flux to less than  $1 \times 10^8$  [ions/s·cm<sup>2</sup>]. Newly developed system uses the backscatter proton and enables to reduce proton dose significantly.

The backscatter angle is 45 degrees [3]. The proton flux can be reduced to the degree of the backscattering cross section and the actual solid angle of the irradiation area. The geometry of the system is shown in Figure 8. As a result, the dose was restricted to less than  $10^7$  [ions/s·cm<sup>2</sup>]. Initial proton flux is monitored by the faraday cup placed co-axially. The distance between the scattering target and the irradiated sample is 160 mm and the inner diameter of the aperture in front of the irradiated sample is 8 mm. Hence the actual solid angle for the scattered ion

particles is as small as 0.063sr so that the irradiation can be considered uniform. By the Silicon Surface Barrier detector placed behind the irradiated sample the energy spectrum of the back scattered ion particles is measured. The energy distribution of the scattered ion particles can be changed by changing the thickness and the materials of target film. Using this system the response of CR-39 to low level irradiation was investigated. Figure 9 (a) is the result of direct irradiation of the initial proton beam to the CR-39 and Figure 9 (b) is the result of the irradiation by the scattered ion particles. Obviously an appropriate dose rate to identify each ion track is the case of the scattered ion particle irradiation (Figure 9 (b)). Each spot on the Figure 9 (b) corresponds a track. Concentrated spot means the concentrated energy deposit by the ion, a large energy loss near the end of the track. Track Spot A is more concentrated than track Spot B in Figure 9 (b). Energy deposit for track Spot B is smaller which means that the ion had have higher energy and the energy loss had been smaller. Figure 9 (c) shows the

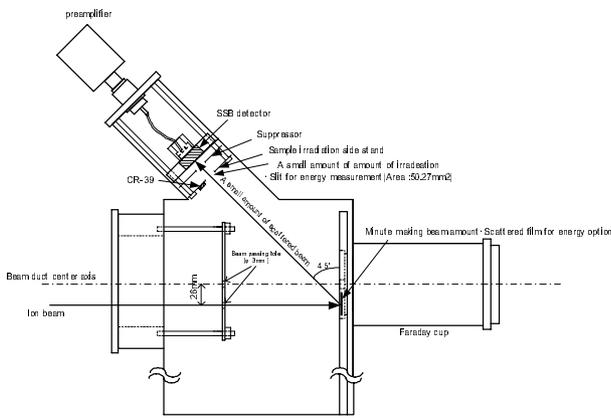


Figure 8: Schematic drawing of new irradiation system.

energy spectrum of the irradiated ion particles generated by the backscattering which was measured by a solid state detector.

## SUMMARY

RAPID, The University of Tokyo is a beam analysis and ion implantation system being used for various application studies. The range of application field extends not only in engineering but also to cultural heritages. Total accelerator operation time of RAPID amounts 9,358 hours since 1995. Recently environmental analysis (pond sediments and atmospheric dust) using PIXE is performed as a student experiment. A special irradiation chamber system was developed which enabled low level irradiation (less than  $10^4$  ions/s  $\text{cm}^2$ ) by means of back scattering. The energy distribution of the back scattering beam is also variable by changing the thickness and materials of the scattered target. Using this system the response of CR-39 track detector to low level irradiation was investigated.

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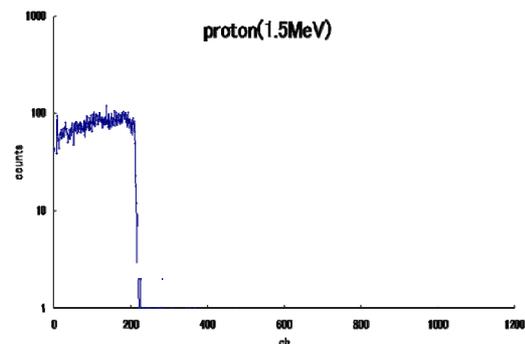
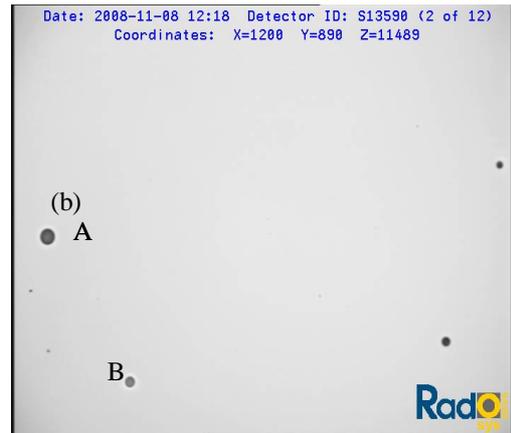


Figure 9: Photograph of the irradiated CR-39 by proton beam; (a) Direct irradiation (b) Backscattered irradiation (c) Energy spectrum of backscattered proton beam transmitting CR-39, which was obtained simultaneously with Figure 9 (b). (Scatter target = 12.5mm thick Al foil).